





## Chronicling 10 Years of Innovation

In 2004, President Bush announced the new Vision for Exploration and NASA launched its Swift and Aura missions — the former to study gamma-ray bursts and the latter to gather ozone and air-quality data. The agency's Solar and Heliophysics Observatory gave Goddard scientists the means to create the first 3D views of coronal mass ejections, powerful eruptions that can cause severe space-weather events. And in October, NASA's Cassini Huygens mission made its first close flyby of Saturn's largest moon, Titan, resulting in images up to 100 times better than anything seen before.

That same month, we released the first edition of a quarterly magazine created to report Goddard technological happenings and how they were helping NASA achieve its mission and goals.

Much has changed over the preceding 10 years, including the magazine's name and branding. What hasn't changed, though, is the magazine's mission. Our purpose remains informing readers of the promising new technologies that could enable scientific discovery and exploration in the future.

In this celebratory issue, we interview Goddard's technology leaders, people who have been intimately involved in shaping the center's technology-development efforts over the past decade. They reflect on the changes that have occurred since the debut of *CuttingEdge* and share their insights on where they think technology development is headed in the future (see page 3).

We're proud of Goddard's technological advances and our community of technologists, scientists, and engineers who are making tomorrow's discoveries possible through the development of new technologies today. Join us in celebrating our 10th birthday chronicling Goddard innovation.

Peter M. Hughes  
Goddard Chief Technologist



### About the Cover:

*CuttingEdge*, formerly known as *Goddard Tech Trends*, celebrates its 10th year of publication this fall. All but three of the magazine's covers are included on the cover to show how the publication changed over the years.

### Clarification:

In the summer issue of *CuttingEdge*, we inaccurately reported that NASA's CubeSat Launch Initiative is funding the development of Goddard's Compact Radiation belt Explorer. In fact, NASA's GEO/LCAS (Low-Cost Access to Space) program is funding the effort.

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# From Scattered and Stove-Piped to Strategic

*Technology-Development Culture Adopted More Disciplined Approach*

Goddard R&D is different today.

Though Goddard's technology-development program had produced innovative capabilities that NASA needed for new missions, it was "wild and wooly," "scattershot," and "unfocused," conceded several technology leaders in a wide-ranging interview to discuss the program's evolution over the past 10 years and where research and development could be headed in the future (see related story below).

"We really didn't have an integrated process for selecting and funding R&D proposals," said Ted Swanson, senior technologist for strategic integration with Goddard's Office of the Chief Technologist, which manages the center's Internal Research and Development (IRAD) program. "All was disconnected, schedule wise, objective wise, nothing was connected."

"It was scattershot," agreed Lisa Callahan, a long-time player in the Goddard R&D community who serves as the associate director for mission planning and technology development in the Earth Sciences Division. "We didn't have a focus on specific areas to make sure technology development supported both Goddard's and NASA's goals and objectives. We were doing new batteries.

We were doing new heat pipes — technologies that we thought were really cool, really innovative — but didn't have a clearly defined application to a flight project."

Since those days of creating "widgets for widgets sake," Goddard technology development decidedly has become more competitive and focused, said Bill Cutlip, senior business-development manager for Earth science. "IRAD proposals get a lot more scrutiny. There is a lot more structure in the program."

From wild and wooly to disciplined, what changed?

## Funding Precipitated Change

According to Callahan, Swanson, Cutlip, and others who helped shape and refine the program over the past 10 years, the most significant precipitator to adopting a more focused and disciplined approach to R&D development was funding.

Ten years ago, NASA had reorganized its Research and Engineering Directorate, also known as Code R, which directed funding to specific individuals and organizations to advance a technological need. Though NASA still invested in technology development, primarily through mission-oriented

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# Gazing Into the Crystal Ball

*What Does the Future Hold?*

What's the next big thing? What does the future hold for technology development at Goddard?

Though no one has a crystal ball, a few trends appear to be emerging — many, once again, motivated by diminished funding for space science and exploration, said leaders of Goddard's technology-development community.

"Look at the overall NASA budget," said Bill Cutlip, a senior business-development manager who specializes in Earth-science technology. "It's flat. We have to realize that \$1-billion missions are not going to be as plentiful in the future. NASA is not going to have a half-billion dollars to spend on an instrument. We have to be even more focused with our investments."

## CubeSats and SmallSats to Take Center Stage

Doing more science for less money in part means deploying instruments on already-existing platforms, such as the International Space Station, and downsizing them so that they fit inside SmallSats and CubeSats, said Goddard technology leaders.

SmallSats are somewhat larger than three-unit (3U) CubeSats, which measure 12 inches long, but still are much smaller than traditional satellites. Since their development more than a decade ago by the university community primarily for instructional purposes, CubeSats, in particular, have

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# Outer Space on a Budget

*Skunkworks Team Set to Deliver New-Fangled 6U CubeSat*

A Goddard “skunkworks” team gave itself just one year to develop, test, and integrate a new-fangled CubeSat that could reliably and easily accommodate NASA-class science investigations and technology demonstrations at a lower cost.

The team is on track to meet its self-imposed deadline.

The team, led jointly by Michael Johnson, the chief technologist of Goddard’s Applied Engineering and Technology Directorate, and Michael Hesse, director of Goddard’s Heliophysics Science Division, is expected to begin environmental testing of a six-unit or 6U CubeSat in late December. Once the team completes thermal vacuum testing, it will deliver the new CubeSat to Cape Canaveral where it then will be readied for launch to the International Space Station for deployment perhaps as early as January 2016.

“Rapid advances in the performance and efficiency of miniaturized systems are enabling a future only limited by vision and imagination,” Johnson said. “CubeSats are a part of that future.”

The CubeSat — known as Dellingr, a name derived from the god of the dawn in Norse mythology — will carry three heliophysics-related payloads (see related story, page 6). It doubles the payload capability of the ubiquitous and proven three-unit or 3U CubeSat pioneered by the California Polytechnic State University in 1999 primarily for the university community.

## Acute Need

The need for such a platform, which measures about 12 inches long, four inches high, and nearly eight inches wide, is acute, Johnson said. “We need a transformational technology that gives us a way to dramatically change the way we do science,” he said. Because NASA science budgets are flat and not likely to increase in the near term, “we need more cost-effective approaches to achieve compelling Earth and space science. A 6U capability provides one way to accomplish the goal,” Johnson explained.

In February 2014, Johnson and Hesse pulled together a small team of Goddard engineers and scientists to develop and implement “lean,” end-to-end techniques, processes, and systems for a 6U CubeSat capable of carrying out formidable

scientific missions. As part of its charter, the Dellingr team was to design, test, and deliver a flight-ready, fully integrated 6U CubeSat by February 2015, at a fraction of the cost of more traditional satellite missions.

The fully integrated Dellingr may be able to hitch a ride on a resupply craft headed for the International Space Station in January 2016, where it would be deployed in a high-inclination orbit similar to the station’s orbital path. Its mission is expected to last up to six months.

Once successfully demonstrated, the team says it will make the platform’s design — implemented with low-cost, commercial off-the-shelf parts — available to any U.S. organization interested in using it.

## The Need for New and Improved CubeSat

Once the domain of university researchers, CubeSats in recent years have increasingly become more popular among government researchers. Motivated in large by their growing capabilities and relatively inexpensive cost, NASA and other government agencies are increasing their investments in CubeSats. NASA now is funding CubeSat mission opportunities through various programs.

In addition to their low cost, CubeSats enable mission configurations not possible with more traditional approaches. Instead of launching just one satellite, mission planners could deploy swarms or constellations of these tiny platforms to execute simultaneous, multi-point observations. Technologists, meanwhile, also are interested in using CubeSats. Before mission planners can infuse a prototype technology, its developers must first demonstrate the technology in a relevant end-to-end space environment. CubeSats have the potential to offer the much-needed access, Johnson said.

However, 3U CubeSats, while adequate, “don’t always offer our scientists the payload volume they require for their missions,” he added.

Disadvantages of the 3U size include more constraints on volume and power, said Chuck Clagett, Dellingr project manager. Furthermore, some studies suggest that previous CubeSats failed 40 percent of the time. By doubling the platform’s

# 6U CubeSat

*A "Skunkworks" team has designed a new-fangled 6U CubeSat and plans to complete its construction and integration by February 2015 for a possible deployment from the International Space Station.*

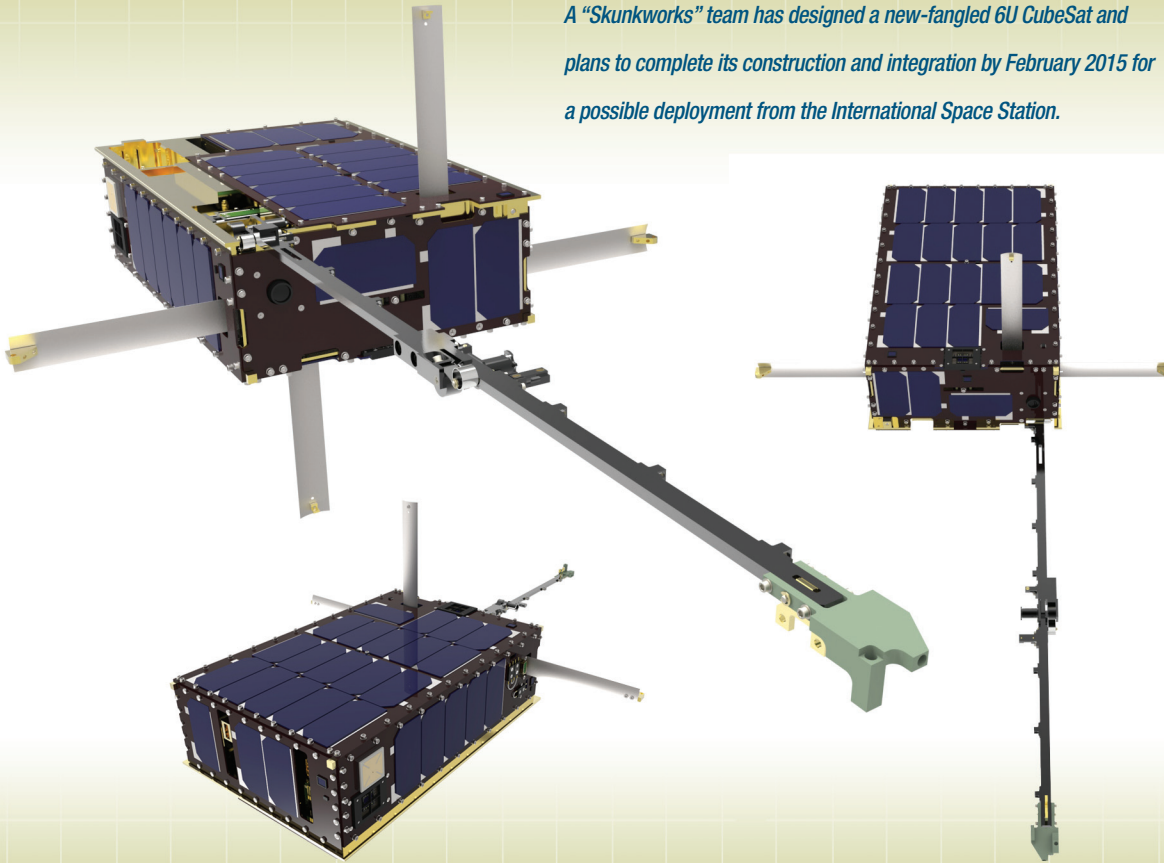


Illustration Credit: Luis H. Santos

girth, increasing its power capacity, and employing novel processes to increase its on-orbit reliability, the team believes it will have created a platform capable of carrying out more robust missions for science. "Our goal is to create a platform that is successful more than 90 percent of the time — similar, in fact, to sounding rocket flights," Clagett added.

## Heliophysics Payloads

Three heliophysics-related payloads will make the maiden journey. One, the miniaturized ion/neutral mass spectrometer, actually will be tested for the first time aboard the National Science Foundation's ExoCube mission, which will measure the densities of all significant neutral and ionized atom species in the ionosphere, the outer region of the atmosphere where incoming solar radiation ionizes

a large fraction of atoms. ExoCube is launching in January 2015. Two magnetometer systems will be demonstrated, as well.

"Dellinger is an innovative, fast-track mission that demonstrates our ability to execute reliable, small science-grade missions inexpensively and rapidly," said Luis Santos Soto, Dellinger deputy project manager and Wallops Flight Facility engineer who has spent the past five years working on CubeSats and developing mechanisms specifically for these tiny craft (*CuttingEdge*, Spring 2014, Page 10). "For us, this is a pathfinder. It symbolizes the dawn of a new age for CubeSats at Goddard." ♦

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# One Big Potentially Groundbreaking Capability

*CubeSat Instruments to Demonstrate NASA Firsts*

The Dellinger six-unit CubeSat, which is taking its developers just one year to design, build, and integrate (see page 4), won't be the only potentially groundbreaking capability for NASA. Its heliophysics payloads also are expected to significantly advance science on tiny platforms.

Making Dellinger's maiden journey perhaps as early as January 2016 are two different magnetometer systems and a miniaturized ion/mass spectrometer. All three received support from Goddard's Internal Research and Development (IRAD) program, said Nikolaos Paschalidis, Goddard's heliophysics technology lead and Dellinger payload manager.

Like their colleagues on the Dellinger-development team, instrument scientists and engineers had just one year to complete their payloads. "Building an instrument in just one year is a challenge," said Paschalidis. "It has been very intense," agreed Todd Bonalsky, a Goddard engineer who designed one of the magnetometer systems. "It will pay back in the end. We have a niche that needs to be filled."

## Never-Before-Flown Magnetometer Systems

According to Bonalsky, NASA currently lacks a low-power, inexpensive magnetometer small enough to fit inside a CubeSat. As a result, the CubeSat community relies on commercial-off-the-shelf magnetometers "that do not have the necessary accuracy or precision for science-grade measurements of the auroral zone," Bonalsky said.

He believes his instrument — coupled with another novel, no-boom magnetometer created by Principal Investigator Eftyhia Zesta — will give the CubeSat community a tool that delivers high-quality, highly accurate data of Earth's magnetic fields for a fraction of the cost. However, he readily concedes his instrument in no way rivals the larger, more robust magnetometers Goddard has built for several interplanetary missions.

"Ours isn't as capable as these heritage magnetometers, but for our purposes we really don't need their level of sophistication or capability. We need something that is less expensive, can fit into a



Eftyhia Zesta and Todd Bonalsky pose with a gimbal table they designed to test CubeSat-compatible magnetometer systems at the Goddard Magnetic Test Facility.

CubeSat, and offer high-resolution, highly accurate data," he said.

Achieving this milestone — which will be a first for CubeSats — involved a marriage of sorts.

All spacecraft generate their own magnetic fields. To prevent those fields from contaminating the magnetic forces scientists actually want to measure, magnetometers are typically placed on a large boom that extends far from the spacecraft. CubeSats, however, don't have the real estate to accommodate such a large device. Therefore, Bonalsky only had room for a 30-inch boom — which is better, but not ideal. "Even when deployed, the magnetometer still will be in a fairly magnetically dirty area," he said.

Enter the no-boom magnetometer system, a versatile capability that promises scientific-grade observations on a variety of platforms, including CubeSats. "It will allow us to take advantage of any potential future ride opportunity due to its easy integration and low requirements on the bus functions," Zesta said.

Comprised of multiple miniaturized fluxgate magnetometer sensors placed inside the satellite bus, the no-boom magnetometer will measure the magnetic fields or "noise" generated by torquers, solar panels, motors, and other hardware on the Dellinger spacecraft. Sophisticated computer algorithms that Zesta's team created then will analyze

both the external and internal magnetometer data to subtract spacecraft-generated noise from the actual science data.

"The Dellinger project is a great opportunity to see how this will work," Bonalsky said, adding that both magnetometer systems will undergo testing at the Goddard Magnetic Test Facility in November. A complete integration must be completed by the end of December.

"Magnetic field measurements are perhaps the most fundamental type of measurement in heliophysics," Zesta said. "CubeSats can offer an inexpensive means to gather these multipoint measurements, which we can use to improve global models."

## History-Making Spectrometer

The third payload, a miniaturized ion/mass spectrometer developed specifically for CubeSats by a team led by Paschalidis and Goddard heliophysicist Sarah Jones, is an improved duplicate of another that will be launched aboard the National Science Foundation-funded ExoCube mission in January 2015 (*CuttingEdge*, Spring 2014, Page 8).

"CubeSats provide easy access to space," said Paschalidis, who, while building the Dellinger payload, completed and delivered the ExoCube instrument to the California Polytechnic State University in July. The university is leading the ExoCube mission. "They offer the potential to discover something of interest in a relatively short period of time and the capability to fly a constellation of CubeSats for simultaneous, multipoint measurements, something which has been the dream mission for many years. That's how the CubeSat business will evolve."

Like its ExoCube sibling, the Dellinger instrument will measure the composition and density of various ions and neutral elements in Earth's lower exosphere and upper ionosphere, a volatile region of the upper atmosphere that affects satellite communications and creates a drag that can degrade satellite orbits. "This will be the first time we will make direct in-situ measurements of hydrogen, and the first time since the era of NASA's Dynamic Explorer-2 in 1981-1983 to make global in-situ measurements of oxygen, helium, and nitrogen," Jones said, referring to ExoCube's science goals. "We're making history with a CubeSat."

This is just the beginning, Paschalidis said. With the mass spectrometer flying on two separate

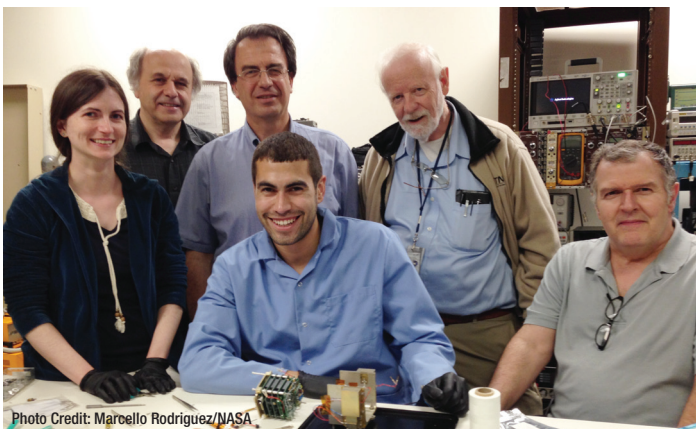


Photo Credit: Marcello Rodriguez/NASA

The team assembling the miniaturized ion/neutralized mass spectrometer — the tiny cube-shaped device sitting on the table — includes (from left, clockwise): Sarah Jones, Dennis Chornay, Nick Paschalidis, Ed Sittler, Tim Cameron (seated, right), and Marcello Rodriguez (seated, center). Team members not pictured include: Paulo Uribe, Giriraj Nanan, George Suarez, and Jeff Dumonthier.

spacecraft, his ultimate goal is to team with others to fly many of these instruments. Together, they could gather simultaneous, multipoint global measurements, which he says are important to understanding the flow of mass and energy in the thermosphere, ionosphere, and magnetosphere. This process causes the upper atmosphere to inflate, creating friction that ultimately brings down satellites and other space assets. "We're going to do more with this instrument," he promised. ♦

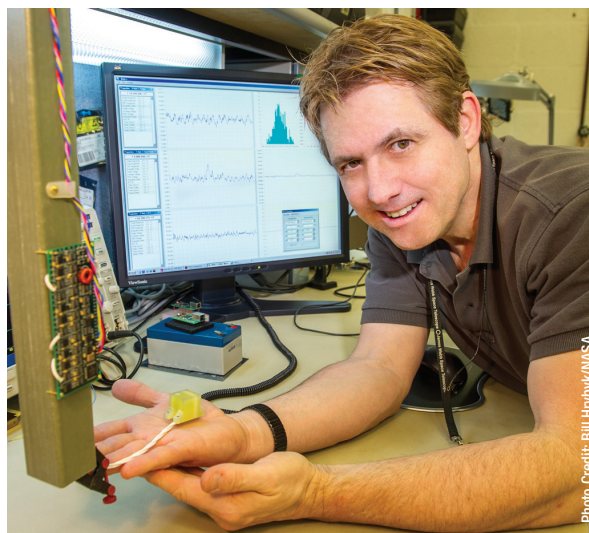


Photo Credit: Bill Hrybyk/NASA

The design engineer of a new magnetometer system, Todd Bonalsky, holds the tiny device while in his laboratory.

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# Return of the GEDI...Two Decades Later

*New Goddard R&D-Funded Probe Wins Earth Venture Award*

For Deputy Principal Investigator Bryan Blair, NASA's selection of a "homegrown" laser-based instrument that will provide a unique 3D view of Earth's forests culminates a journey he began more than 20 years ago.

"This is a great science mission," said Blair, who used R&D program funding to pioneer the lidar-measurement technique that will make NASA's new \$94-million Global Ecosystems Dynamics Investigation (GEDI) possible. "We've wanted to get this measurement for 20 years. It's been a long road."

When the GEDI instrument begins operations on the International Space Station in 2019, it will be the first to systematically probe the depths of the forest canopy over the tropics and the tundra in the high-northern latitudes. The goal is to help fill in missing details about the role of forests in the carbon cycle. The system is one of two instrument proposals recently selected for NASA's Earth Venture Instrument program.

By revealing the 3D architecture of forests in unprecedented detail, GEDI will provide crucial information about the impact that trees have on the amount of carbon in the atmosphere, Blair said. Although it's well established that trees absorb some carbon and store it long term, scientists have not determined exactly how much carbon forests contain. As a result, it's not possible to determine how much carbon would be released if a particular tract of forest were destroyed, or how well emissions could be countered by planting new trees.

"Of all the components of the carbon cycle, the piece we understand the least is the net balance between forest disturbance and regrowth," said Ralph Dubayah, the GEDI principal investigator at the University of Maryland, College Park. "GEDI will help scientists fill in this missing piece by revealing the vertical structure of the forest, which is information we really can't get any other way."

## GEDI Traces Heritage to LVIS

GEDI can do this because of the lidar technology that Blair began developing shortly after he joined NASA in the early 1990s. The first instrument he created — Goddard's Land, Vegetation and Ice



Image Credit: Bill Hrybyk/NASA

Principal Investigator Bryan Blair began developing his "homegrown" laser instrument to gather data about the role of forests in carbon storage.

Sensor (LVIS) — flies on high-altitude aircraft and uses a slightly different technique to detect subtle variations in forest, land topography, ice sheets, glaciers, and sea ice (*Goddard Tech Trends*, Winter 2008, Page 6).

From his experience with LVIS, Blair improved his technique to create an instrument that could carry out the same science, but from space — a first-ever capability.

GEDI will carry a trio of specialized lasers, developed in-house at Goddard, and will use sophisticated optics to divide the three beams into 14 tracks on the ground. Together, these tracks will be spaced 1,640 feet (500 meters) apart on the surface, creating a total swath width of about 4 miles (6.5 kilometers). GEDI will sample all land between 50 degrees north latitude and 50 degrees south latitude.

"One thing that makes a laser-based instrument different is that it 'sees' the same thing the human eye sees. It uses light," Blair said. The lasers will ping the surface with brief pulses of light that are optimized to pass through the canopy of even very dense forests. The team estimates that the instrument will transmit 16 billion pulses in one year.

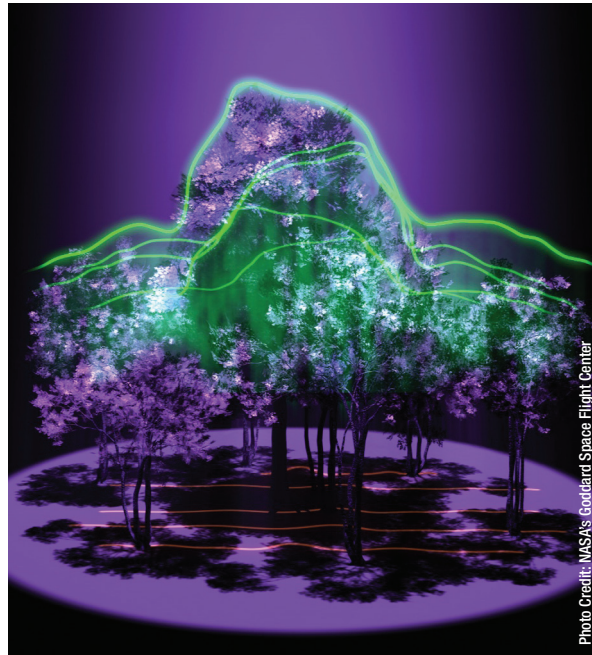
A small fraction of each pulse — the return pulse — bounces back to a detector on the orbiting instrument. The materials that a pulse encounters along the way will modify the signal slightly, result-

ing in a different fingerprint when a pulse interacts with leafy treetops versus woody trunks or the ground. These fingerprints will provide enough detail to measure the height of the trees and where the leaf canopy begins with an accuracy of 3-1/3 feet (1 meter). From this information, scientists will be able to estimate how much the trees weigh and, in turn, how much carbon they are storing.

## More Powerful Toolset

By combining these findings with satellite maps showing where development and deforestation are taking place or with studies revealing the composition of forests, scientists will have a more powerful toolset for addressing questions about land use, habitat diversity, and climate effects, Dubayah said. For example, researchers would be able to determine the age of trees in specific forests. They also might be able to relate forest architecture with habitat quality and biodiversity of birds. The ultimate goal, Dubayah said, is to be able to monitor these and other changes in forests over time.

"This is the first time we've done highly accurate, high-resolution mapping to measure forest biomass from space," Blair said. "This wouldn't have been possible for us without support from Goddard's R&D programs over the years. This is a home-grown instrument and a homegrown technique." ♦



*The Global Ecosystem Dynamics Investigation lidar will reveal the 3D architecture of forests, as depicted in this artist's concept. The unprecedented detail of these measurements will provide crucial information about the impact that trees have on the amount of carbon in the atmosphere.*

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# Creating a Virtual Telescope

*Engineer Advances Technology for Tandem Observations*

Although scientists have flown two spacecraft in formation, no one ever has aligned the spacecraft with a specific astronomical target and then held that configuration to make a scientific observation — creating, in effect, a single or “virtual” telescope with two distinctly different satellites.

A Goddard team, led by aerospace engineer Neerav Shah, not only is developing the guidance, navigation, and control (GN&C) technology needed to execute such an exacting orbital configuration, but also is planning to demonstrate the capability on two CubeSats — in itself a NASA first. Working in tandem, the two tiny satellites would create a high-resolution solar coronagraph to examine the sun's outermost plasma layer, the corona, where powerful eruptions called coronal mass ejections take form.

Such a capability would benefit studies of the sun as well as a number of other scientific disciplines — especially those requiring dual spacecraft to detect Earth-like planets in other solar systems or even image the event horizon of a black hole, the point of no return where nothing can escape the black hole's intense gravitational pull, Shah said.

"Many virtual-telescope mission concepts have been conceived and proposed," Shah said. "One of the main reasons they are not selected for funding is because the systems-level capability to align two spacecraft to an inertial source isn't mature enough for projects to take the risk. Now is the time to advance the technology's readiness so that we can confidently propose and win these types of missions, which, I believe, will revolutionize astrophysics and heliophysics."

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## Virtual, *continued from page 9*

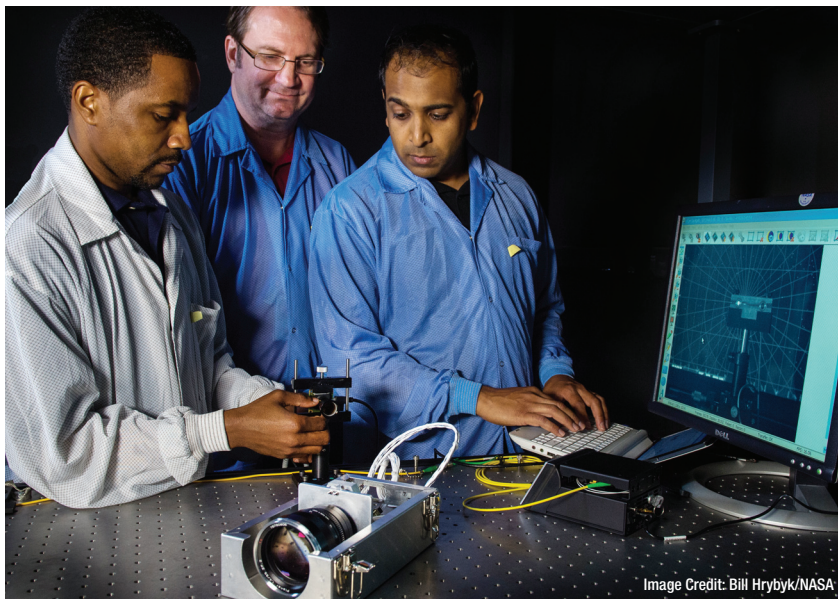
Under Shah's technology-development effort, funded by Goddard's Internal Research and Development (IRAD) program, the team is working with the Maryland-based Emergent Space Technologies to advance and test commercial-off-the-shelf navigation and relative-position sensors, actuators, cross-communication links, as well as in-house developed GN&C algorithms. The team also is leveraging an \$8.6-million investment from the Defense Advanced Research Projects Agency. Together, the system would determine the inertial alignment of the two spacecraft, both aligned with a specific target, and then independently adjust their positions to maintain and control the configuration.

With the IRAD support, the team plans to develop a prototype system — the so-called Virtual Telescope Alignment System (VTAS) — and subject it to a series of rigorous ground demonstrations. The team's ultimate goal is to demonstrate VTAS on two CubeSats, relatively low-cost platforms that offer technologists less-risky opportunities to test and demonstrate new technologies. Once demonstrated, Shah and his team believe the technology then could be ripe for infusion into a dual-spacecraft mission.

Developing a formation-flying capability to form a multi-spacecraft observatory is of extreme interest to the worldwide community. A number of technology-development missions currently are underway.

Under Shah's baseline mission, the team would launch the satellites into a low-Earth orbit. One of the tiny spacecraft would be equipped with a communication crosslink, thrusters, GN&C software, and occulter — a small disk used in a telescope to block the view of a bright object so that scientists can observe the fainter one, such as the sun's corona. The other — positioned about 60 feet (20 meters) behind its sibling — would carry the coronagraph, a laser beacon, and communications equipment.

Aligned toward the sun, the two-satellite virtual telescope would study the sun's corona, and more



Sean Semper (left), Phil Calhoun, and Neerav Shah are advancing the technologies needed to create a virtual telescope that they plan to demonstrate on two CubeSats. The tiny platforms would work together as a high-resolution solar coronagraph to examine the sun's outermost plasma layer, the corona, where powerful eruptions called coronal mass ejections take form.

particularly, the size and scope of solar eruptions that race across the solar system, sometimes crashing into Earth's magnetosphere and causing severe space-weather events.

Shah, along with Joe Davila, senior scientist in Goddard's Heliophysics Science Division, and Phil Calhoun, a Goddard senior aerospace engineer, conceived the solar-coronagraph mission because such a capability is a high-priority science goal.

Furthermore, its architecture is nearly identical to one that an exo-planet mission might use in its hunt for Earth-like planets around other stars. Both rely on an occulter mask to block starlight. However, the solar coronagraph is less challenging to demonstrate. The angular resolution needed to image the sun's corona is on the order of arcseconds, which is far less demanding than the milli-arcsecond requirement for a planet finder, Shah said.

"Enabling the solar coronagraph paves the way for the more demanding missions," such as X-ray imaging of solar flares, he added. "Once you fly a virtual telescope with looser formation requirements, you open up the space for others to follow and improve on the accuracy," Shah said. ♦

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## Scattered, *continued from page 3*

technology-development programs, directed funds became increasingly rare. Goddard technologists no longer could assume that NASA would fund their projects as it had in the past.

Also feeling the funding pinch, Goddard, meanwhile, had begun reorganizing its R&D program, consolidating multiple funding mechanisms into one more easily managed IRAD program.

As part of the overhaul, Goddard decided to primarily manage its R&D program along science-based “lines of business,” specific disciplines in which Goddard had traditionally excelled, including Earth science, heliophysics, planetary and lunar science, and astrophysics.

It also decided to invest the lion’s share of its modest resources in mission concepts and technologies that were going to be competed in near-term calls for proposals, thereby advancing the technology-readiness level and increasing the probability of winning. Under the new management approach, IRAD principal investigators were required to show how their research mapped to these disciplines and benefited identified missions.

“Our budget was and remains tight,” Cutlip said. “This wasn’t manna from heaven. It’s very precious; so we had to maximize our return on investment.”

Goddard also began encouraging scientists and engineers to collaborate more closely, not only in the development of new technology, but also in conceiving technologies that would help scientists answer compelling scientific questions. Goddard’s Sciences and Exploration Directorate (SED) and Applied Engineering and Technology Directorate (AETD) established the Research Engineering Program, which allowed engineers and scientists to co-locate to advance specific concepts in what Callahan called mini-technology incubators. “It really was a positive change,” she said.

Michael Johnson, another long-time leader in Goddard’s technology community, agreed. “Two of Goddard’s strengths are the talent and the close engagement of our scientists and engineers,” said Johnson, who now serves as AETD’s chief technologist. “Great ideas happen when great minds collide. And we’re doing all we can to initiate these

science-engineering collisions.”

While many of these changes have produced a greater return on investment, Goddard has continued to tweak its IRAD program, these experts added. In recent years, the IRAD program has set aside more funding for early-stage innovation. “Initially, we focused heavily on technologies needed by flight programs,” Cutlip said. “But we do need a spectrum of technologies that run the gamut, from very early-stage to the more mature.”



Leaders of Goddard’s technology community reflected on how R&D has changed over the past 10 years. Front: Mike Johnson; back: Ted Swanson, Bill Cutlip, Lisa Callahan, and Azita Valinia.

## Competition Remains Common Denominator

What hasn’t changed, however, is that technologists must compete for IRAD funds, all agreed.

“What I like about the current various technology programs at NASA is that a majority of them are awarded through competition,” said Azita Valinia, the SED associate director for research and development. “Over the past 10 years, we have made great strides focusing and aligning the technology development at Goddard to our core business. This has had a great payoff. We are more competitive. It also enabled us to infuse the technologies in future science missions. I am very proud of this accomplishment.” ♦

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# Ultra-Black Nano-Coating to Be Tested in Space

*Carbon-Nanotube Material Applied to 3D Baffle*

*Right: This is a close-up view of a baffle that will be coated with the ultra-black carbon-nanotube coating.*

*Both items shown here are not to scale*

*Below: A new carbon-nanotube coating is one of several materials to be tested on the International Space Station as part of the Materials Coating Experiment. The super-black material occupies the "D" slot on the sample tray.*



Photo Credit:  
Paul Nikulla/Goddard Code 544

Photo Credit:  
Bill Squicciarini/NASA

An emerging super-black nanotechnology will be tested for the first time this fall on the International Space Station and, in another potentially groundbreaking application, it will be applied to a complex, 3D-shaped component critical for suppressing stray light in a smaller, less-expensive solar coronagraph designed to fly on the orbiting outpost or as a hosted payload on a commercial satellite.

The super-black carbon-nanotube coating, whose development is six years in the making, is a thin, highly uniform coating of multi-walled nanotubes made of pure carbon about 10,000 times thinner than a strand of human hair. It is considered especially promising as a technology to reduce stray light, which can overwhelm faint signals that sensitive detectors are supposed to retrieve.

## Hitching Ride on NASA's RRM Payload

"Though tested extensively in ground-based laboratories and aircraft instruments, our super-black nano-material has never flown in space," said John Hagopian, an optics engineer who has pioneered the technology's development. "The objective is to

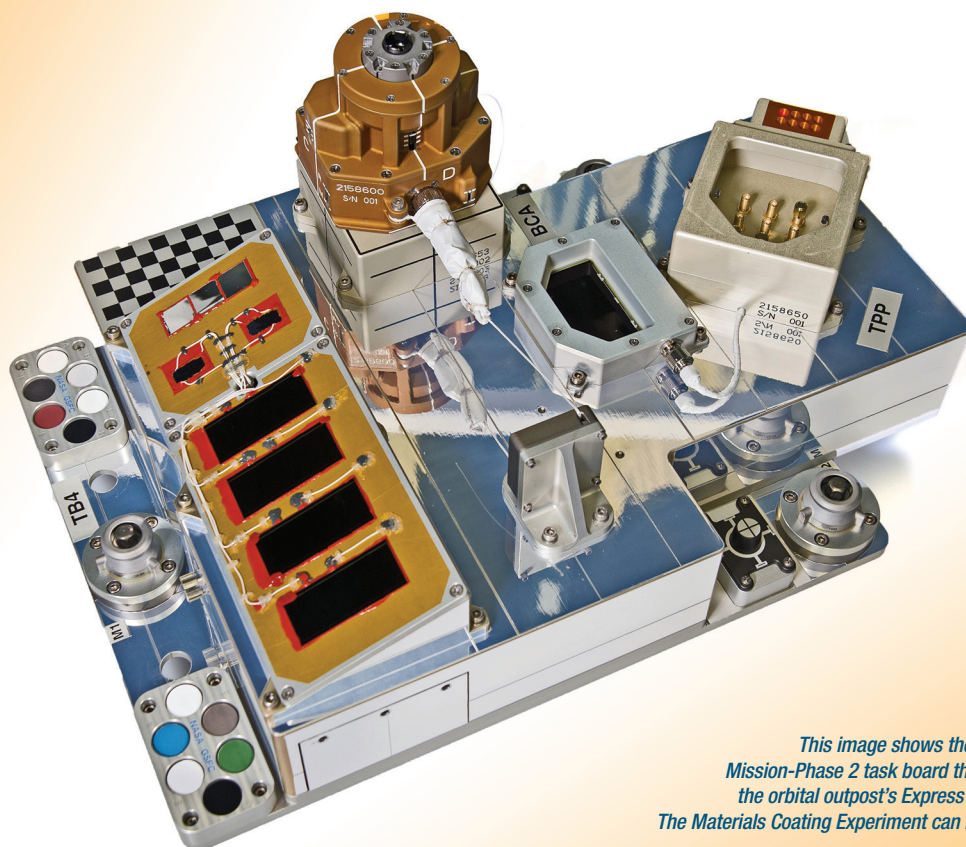
determine how well this coating survives the harsh space environment."

To determine the coating's performance, Hagopian prepared two nanotube-coated titanium discs, which were included in a materials experiment that hitched a ride to the International Space Station as part of NASA's Robotic Refueling Mission-Phase 2, launched in late July. During its one-year stay, the experiment will be exposed to harsh radiation and other elements. Knowing whether the coating can withstand the extreme environmental conditions will help further qualify the technology for potential use on space-based instruments, Hagopian said.

"We've made great progress on the coating," Hagopian said. "The fact the coatings have survived the trip to the space station already has raised the maturity of the technology to a level that qualifies them for flight use. In many ways the external exposure of the samples on the space station subjects them to a much harsher environment than components will ever see inside of an instrument."

Although other NASA researchers have flown carbon nanotubes on the orbiting outpost, their

Photo Credit: Chris Gunn/NASA



*This image shows the Robotic Refueling Mission-Phase 2 task board that was installed on the orbital outpost's Express Logistics Carrier 4. The Materials Coating Experiment can be seen on the left.*

samples were designed for structural applications, not stray-light suppression — a completely different use requiring that the material demonstrate greater absorption properties.

Ground-based testing has proven its robust absorption capabilities. Reflectance tests have shown that the coating absorbs 99.5 percent of the light in the ultraviolet and visible and 99.8 percent in the longer infrared bands due to the fact that the carbon atoms occupying the tiny nested tubes absorb the light and prevent it from reflecting off surfaces. Because only a tiny fraction of light reflects off the coating, the human eye and sensitive detectors see the material as black — in this case, extremely black.

As a result, technologists believe the coating could potentially replace state-of-the-art black paint that instrument developers currently apply on baffles and other instrument components to reduce stray light.

### Applying Technology to Baffles

In the meantime, Hagopian and his team plan to apply the carbon-nanotube coating on a complex, cylindrically shaped baffle — a component that

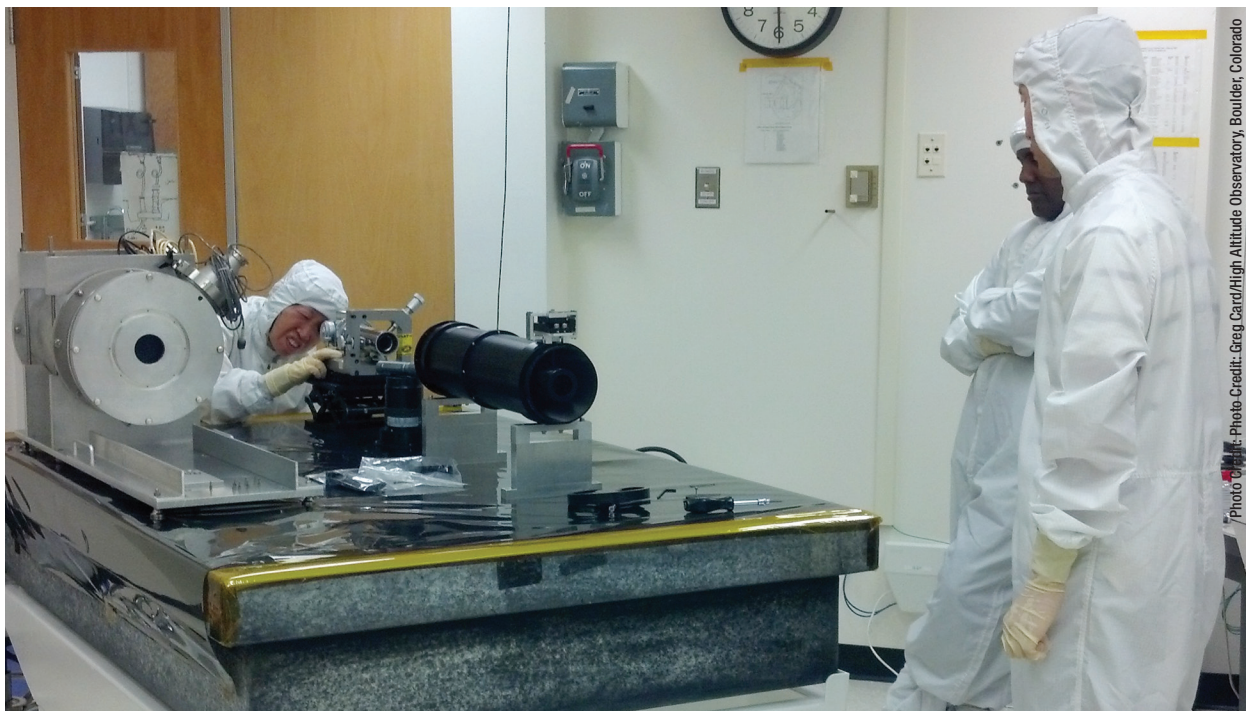
helps reduce stray light in telescopes. The effort will help determine whether the carbon nanotubes are as effective as black paint in this particular application.

"We have to have the right optical system and the best baffles going," said Doug Rabin, a Goddard heliophysicist who studies diffraction and stray light in coronagraphs. Of particular interest to him is how the coating could benefit a new compact solar coronagraph now being developed by Goddard Principal Investigator Nat Gopalswamy and optical designer Qian Gong.

Preventing stray light is an especially tricky challenge for Gopalswamy's team.

The new compact coronagraph — designed to reduce the mass, volume, and cost of traditional coronagraphs by about 50 percent — will use a single set of lenses, rather than a conventional three-stage system, to image the solar corona, and more particularly, coronal mass ejections. These powerful bursts of solar material erupt and hurdle across the solar system, sometimes colliding with Earth's protective magnetosphere and posing significant hazards to astronauts and infrastructure in space and on Earth.

*Continued on page 14*



Goddard optical designer Qian Gong looks at the coronagraph she is developing through an alignment telescope at the High Altitude Observatory. She plans to test a carbon-nanotube coating to be applied to the coronagraph's 3D baffle.

## Coating, *continued from page 13*

"Compact coronagraphs make greater demands on controlling stray light and diffraction," Rabin explained, adding that the corona is a million times fainter than the sun's photosphere. Coating the baffle or occulter with the carbon-nanotube material should improve the component's overall performance by preventing stray light from reaching the focal plane and contaminating measurements.

## Designed for the Space Station

The project is well timed and much needed, Rabin added.

Currently, the heliophysics community receives coronagraphic measurements from the Solar and Heliospheric Observatory (SOHO) and the Solar Terrestrial Relations Observatory (STEREO). "SOHO, which we launched in 1995, is one of our Great Observatories," he said. "But it won't last forever." Although somewhat newer, STEREO has operated in space since 2006. "If one of these systems fails, it will affect a lot of people inside and outside NASA, who study the sun and forecast space weather. Right now, we have no scheduled mission that will carry a solar coronagraph."

Gopalswamy's instrument, however, could fill a potential gap in coverage. He and his team have specifically designed the instrument to fly on the

International Space Station or as a hosted payload on a communications satellite or some other spacecraft, Rabin said. "We would like to get a compact coronagraph up there as soon as possible," Rabin said. "We have extreme stray light requirements. Let's see how this turns out."

Given the need for a compact solar coronagraph, Hagopian said he's especially excited about working with the instrument team. "This is an important instrument-development effort, and, of course, one that could showcase the effectiveness of our technology on 3D parts," he said, adding that the lion's share of his work so far has concentrated on 2D applications.

By teaming with Goddard technologist Vivek Dwivedi, Hagopian believes the baffle project now is within reach. Dwivedi is advancing a technique called atomic layer deposition (ALD) that lays down a catalyst layer necessary for carbon-nanotube growth on complex, 3D parts (*CuttingEdge*, Summer 2013, Page 4). "Previous ALD chambers could only hold objects a few millimeters high, while the chamber Vivek has developed for us can accommodate objects 20 times bigger — a necessary step for baffles of this type," Hagopian said. ♦

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# New Remote-Sensing Instrument to Blaze a Trail on the International Space Station

The Cloud-Aerosol Transport System (CATS), a new instrument that will measure the character and worldwide distribution of the tiny particles that make up haze, dust, air pollutants, and smoke, will do more than gather data once it's deployed on the International Space Station in December.

"CATS is a groundbreaking science and technology pathfinder," said Colleen Hartman, Goddard deputy center director for science, operations, and performance. "Not only will it make critical measurements that will tell us more about the global impact of pollution, smoke, and dust on Earth's climate, it will demonstrate a promising new technology and prove that inexpensive missions can make critical measurements needed by the modelers to predict future climate changes."

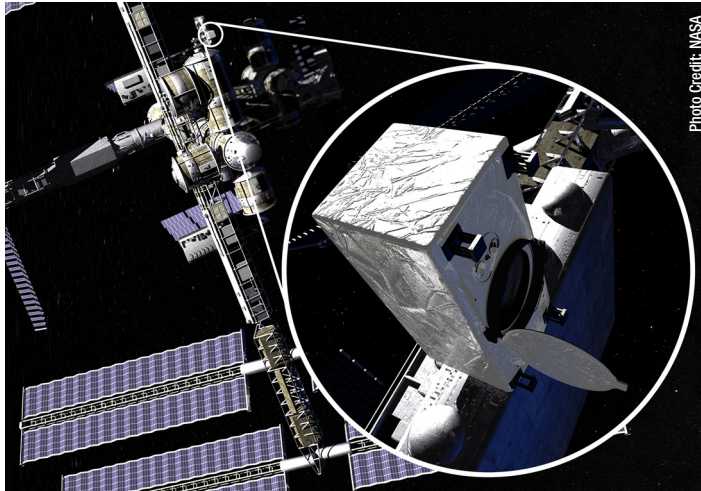


Photo Credit: NASA

*This artist's rendition of the Cloud-Aerosol-Transport System (CATS) shows its location on the International Space Station where it will measure the character and worldwide distribution of the tiny particles that make up haze, dust, air pollutants, and smoke.*

## A Technological First

Technologically, NASA has never before flown an instrument like CATS.

Developed by a Goddard team led by scientist Matt McGill, the refrigerator-size CATS will demonstrate for the first time three-wavelength laser technology for measuring volcanic particles and other aerosols from space. It is intended to operate for at least six months and up to three years aboard the Japanese Experiment Module-Exposed Facility, augmenting measurements gathered by NASA's CALIPSO (Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations) mission.

However, the big difference between the two is that CALIPSO uses two wavelengths — the 1064 and 532 nanometer wavelengths — to study the same phenomena.

That's not the only difference, McGill said. CATS, which was developed with NASA and Goddard R&D funding, also carries extremely sensitive detectors that can count individual photons, delivering better resolution and finer-scale details. It also will fire 5,000 laser pulses per second, using only one millijoule of energy per second. In sharp contrast, CALIPSO delivers 20 laser pulses per second, using a whopping 110 millijoules of energy in each of those pulses.

"As a pathfinder mission, what we're trying to

determine is whether the addition of the third wavelength — 355 nanometers, which is in the ultraviolet — will produce the results we expect it to generate," McGill said. "We believe it will deliver more detailed information revealing whether the particles scientists see in the atmosphere are dust, smoke, or pollution." Though it adds an advanced capability, particularly when coupled with the new detectors, engineers believe the ultraviolet wavelength may be particularly susceptible to damage caused by contamination, McGill said.

"If you get contamination on any of your outgoing optics, they can self-destruct, and then your system's dead. You end up with very limited lifetime. The way to find out is to fly a relatively inexpensive payload aboard an existing platform, like the International Space Station."

## The Future of Technology Demos

"What excites us so much about CATS is the fact that it will add to the observations of the aging CALIPSO," Hartman added. "It also will show that inexpensive missions, like CATS, can be installed on the space station, pointing nadir, to make critical measurements over months at a time. Think of all the Earth-observing science that might be done in a cost-effective manner from the International Space Station." ♦

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# Team Advances Next-Generation 3D-Imaging Lidar

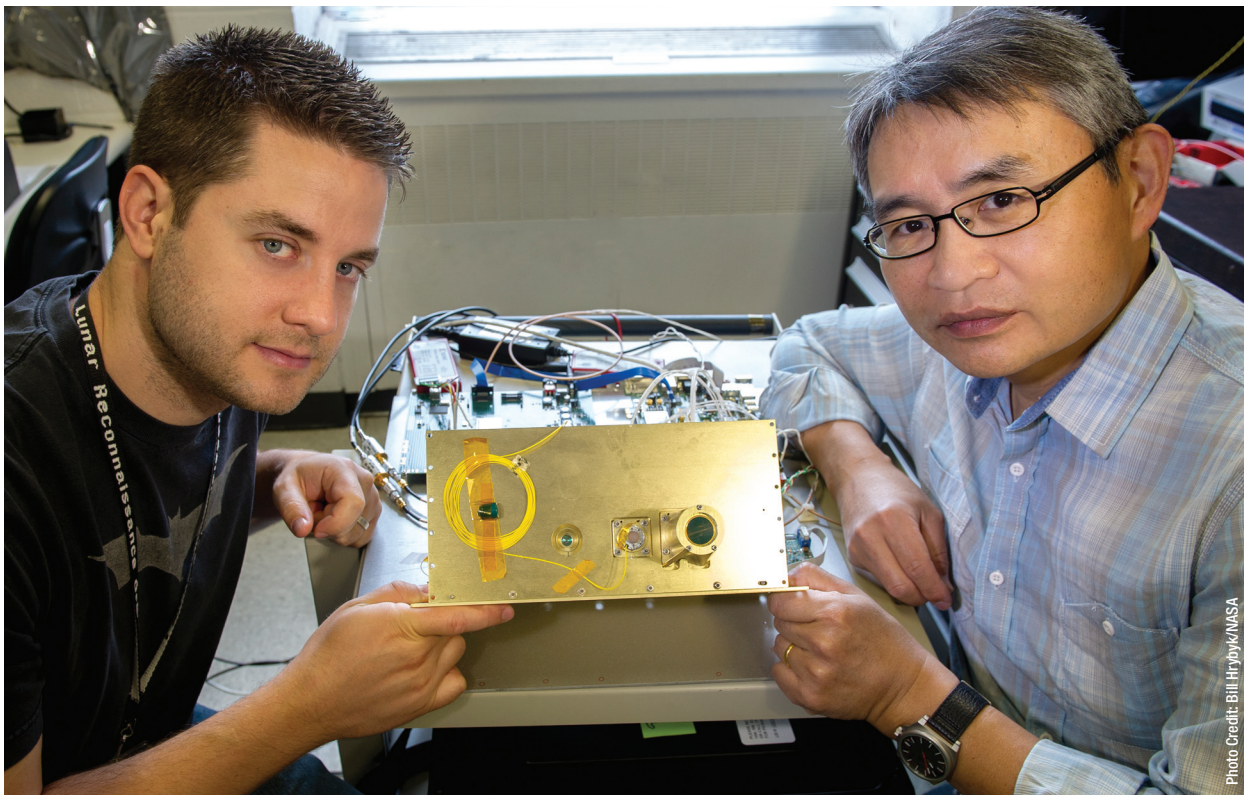


Photo Credit: Bill Hrybyk/NASA

Nat Gill and Tony Yu are developing new lidar systems for satellite servicing and close approaches to asteroids. They are shown here with hardware they have developed for the Goddard Rendezvous Solid-state Scanning Lidar.

Building, fixing, and refueling space-based assets or rendezvousing with a comet or asteroid will require a robotic vehicle and a super-precise, high-resolution 3D-imaging lidar that will generate real-time images needed to guide the vehicle to a target traveling at thousands of miles per hour.

A team of Goddard technologists now is developing a next-generation 3D-scanning lidar — dubbed the Goddard Reconfigurable Solid-state Scanning Lidar (GRSSLi) — that could provide the imagery needed to execute these orbital dances. “We have made a tremendous amount of progress,” said Nat Gill, GRSSLi principal investigator. “We have a long way to go, but we hope to validate the GRSSLi system this fall.”

The current system has achieved a technology-readiness level of five. In the parlance of NASA engineers, this means that once the team completes this iteration of GRSSLi, the team will be ready to build another system that would undergo vibration and thermal-vacuum testing.

GRSSLi is a next-generation scanning lidar based on technologies developed by the Army Research

Laboratory, which later transferred the technology to Spectrolab, Inc., a wholly owned subsidiary of The Boeing Co. The company now markets the instrument as the SpectroScan 3D.

GRSSLi, however, will take 3D-imaging lidar to the next level — all from a small, low-cost, low-weight platform capable of centimeter-level resolution over a range of distances, from meters to kilometers, said GRSSLi Co-Investigator Tony Yu, who received Goddard Internal Research and Development (IRAD) program funding to help advance GRSSLi and its close cousin, a non-scanning 3D-imaging lidar.

Equipped with a low-power, eye-safe laser, a micro-electro-mechanical scanner, and a single photodetector, GRSSLi will “paint” a scene with the scanning laser and its detector will sense the reflected light to create a high-resolution 3D image at kilometer distances — a significant increase in capability over current imaging lidars that are effective only at meter distances. Just as important, the instrument is equipped with onboard “vision” algorithms or software that interpret the three-

dimensional image returned by the lidar. These algorithms estimate location and attitude — or in other words, the pose — of a target relative to the lidar.

“The SpectroScan 3D is a low-cost lidar, but it can’t provide centimeter-level (less than an inch) resolution beyond 30 meters (98 feet),” Yu said. “We are retrofitting this lidar system with a high-energy laser system to extend the range to beyond one kilometer.” GRSSLi currently has a limited range of about 66 feet (20 meters), Yu said. This year, the goal is to extend the range to 0.6 miles (100 meters) by increasing the power of the laser transmitter and adding a more sensitive detector.

The lidar, however, wouldn’t be limited to servicing and repairing satellites and other orbiting assets, Yu said. Under the same IRAD task, Yu and Gill are working to advance a non-scanning version of GRSSLi that would be ideal for close approaches to asteroids. “We view the 3D-scanning lidar as an intermediate step to a non-scanning lidar system,” Yu said.

This particular instrument would employ a flash lidar, which doesn’t paint a scene with a mechanical scanner, but rather illuminates the target with a single pulse of laser light — much like a camera flash.

The advantage is the elimination of moving parts that could be prone to failure. A telescope then would capture the returning photons and image them on a photon-sensitive detector array. Each pixel of that array would measure the photons’ times of flight to create a 3D image of the target.

Although flash lidars are available commercially — and, in fact, one is baselined for the Goddard-led OSIRIS-REx mission — they do not produce high-resolution images from kilometer distances,

a capability that would benefit science and military applications, Yu said.

“A need exists for long-to-short range, low-cost, reliable multifunctional imaging lidars, not only for asteroid rendezvous and planetary rovers, but also for satellite servicing,” Yu said. “We are making progress, but we have a way to go.” ♦

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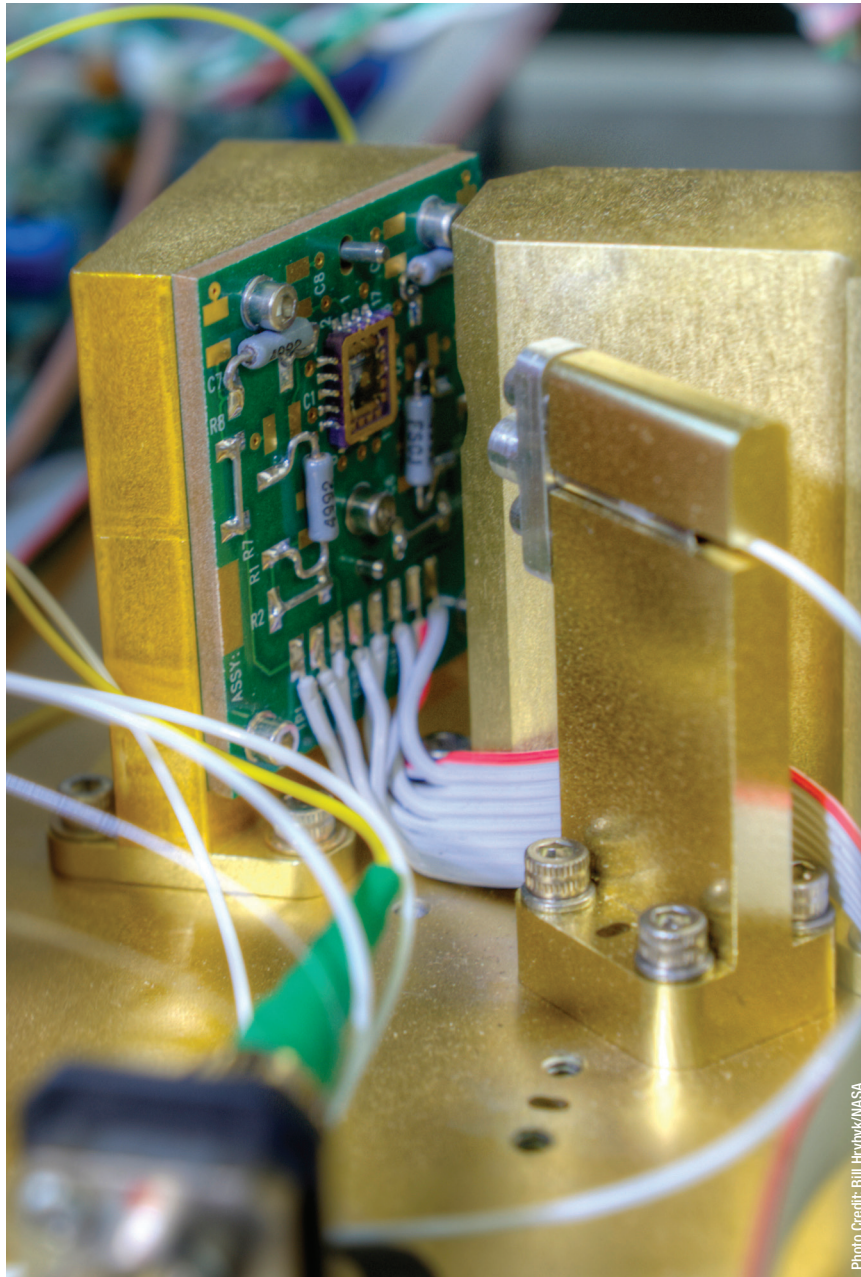


Photo Credit: Bill Hrybyk/NASA

*The micro-electro-mechanical — or MEMS — mirror at the center of the circuit board provides the scanning function in the Goddard Rendezvous Solid-state Scanning Lidar.*

# Team Proposes to Use Laser to Track Orbital Debris

As participation in space exploration grows world-wide, so does the impact of orbital debris — man-made “space junk” that poses hazards to spacecraft and astronauts should they cross paths and collide.

Goddard researchers Barry Coyle and Paul Stysley want to develop a method to define and track orbital debris using laser ranging. This promising approach could overcome shortfalls with passive optical and radar techniques, which are used today to locate and track dead satellites and spacecraft components. These remnants can travel four-to-five miles per second in low-Earth or geosynchronous orbits, where most space assets reside, posing hazards to live spacecraft.

Inspired by an Australian study that found laser tracking increased the accuracy of debris ranging by a factor of 10 when compared with other methods, Coyle and Stysley now “want to reproduce the results from this paper on a larger scale,” using Goddard’s Geophysical and Astronomical Observatory (GGAO).

GGAO’s 48-inch telescope, which transmits outgoing and receives incoming laser beams, has ranged to retroreflector-equipped spacecraft at planetary distances. It also has calibrated and tested the performance of some of Goddard’s altimetry spacecraft.

To show the effectiveness of laser tracking, the team plans to update the GGAO laser from its current 1.064 microns to 1.57 microns, making it safe to project large amounts of energy into the atmosphere without violating aircraft eye-safety standards. Coyle and Stysley would shine the laser light into the sky to find the debris and use the returned light to help estimate a trajectory and find a possible range for movement. With each pass, the added data would increase accuracy.

With this technique, NASA could learn more about debris shape, size, orbital projection, and range, Coyle said. It also could track softball-size objects to an accuracy of a meter, depending on the object’s shape and size. The end result, Coyle said, is a potentially better tracking technique.

Optical telescopes, for example, can track sunlit debris, but they provide little information about the altitude of the debris. Furthermore, optical-based calculations are limited to sunset and sunrise, when the sun illuminates the object against a dark

*Barry Coyle, working with Paul Stysley to develop a laser technique for tracking orbital debris, stands next to the laser-ranging telescope at Goddard’s Geophysical and Astronomical Observatory. The observatory would be the test site for the laser technique.*

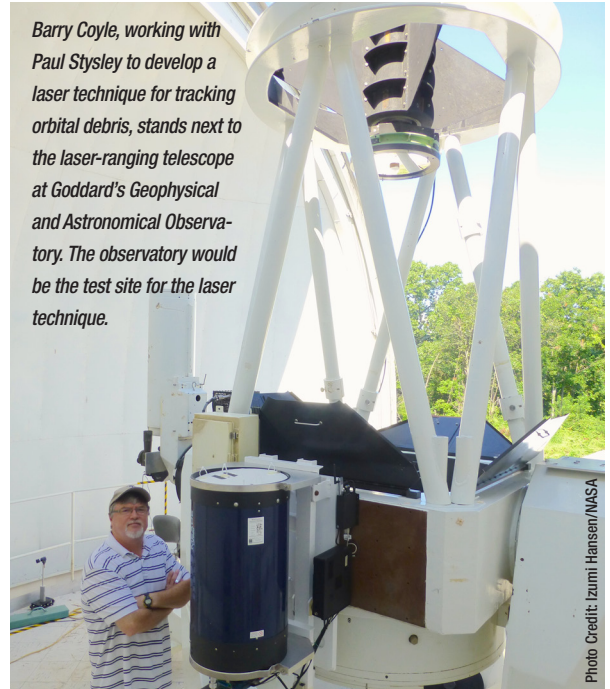


Photo Credit: Izumi Hansen/NASA

sky. Radar, meanwhile, provides a range, rather than the precise location of the orbital debris. Instantaneous positioning is typically accurate to hundreds of meters. Due to drag from solar winds and particles, the orbit changes, meaning that its predicted location envelope will grow quickly by kilometers.

Once the team demonstrates ranging with a target not equipped with the retro-reflector, it would like to implement the technique in a global network of ground-based laser observatories to assist the world’s current debris-tracking efforts.

“Orbital debris affects everybody,” said Coyle, referring to the near collision in 2012 of the Fermi Space Telescope with Cosmos 1805, a defunct satellite. “What’s essential is that these assets are tracked and monitored to protect active and future missions from potentially harmful collisions,” Coyle said.

“Goddard was the birthplace of satellite laser ranging, and manages a world-wide network of ground stations for geophysical applications,” he added. “We want new technology to flow through Goddard and a possible new network, as well.” ♦

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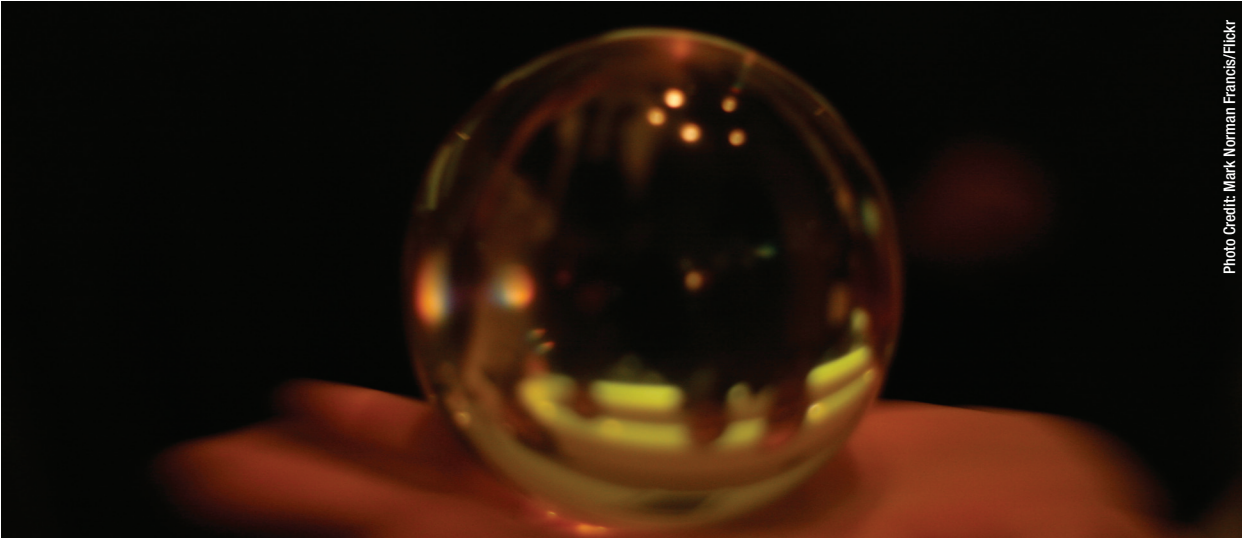


Photo Credit: Mark Norman Francis/Flickr

## Crystal Ball, *continued from page 3*

become increasingly more popular with NASA and the U.S. military. Both are funding new technologies and techniques to improve their overall performance (see related story, page 4).

Given their relative low cost and ease of integration, one trend to watch is how scientists use these increasingly more popular platforms, experts said. One idea gaining more traction these days is using CubeSats as a distributed network — that is, flying a large number of these tiny satellites as a constellation to gather simultaneous, multi-point observations — rather than deploying one large monolithic spacecraft or even a single CubeSat performing a single mission from a particular point in the sky.

"I think Goddard can be very successful if it steers the competition in the direction of distributed architecture with CubeSats rather than focusing on a one-CubeSat-at-a-time business model," said Azita Valinia, associate director for research and development for Goddard's Sciences and Exploration Directorate and a long-time leader in the center's R&D community.

In addition to serving science, CubeSats also support technology demonstrations helping to advance early-stage technologies deemed too risky for full-scale missions. And over the past few years, Goddard technologists certainly have taken advantage of the opportunity. They continue to win CubeSat berths to test-drive new approaches that they could one day infuse into larger, more comprehensive missions (see page 6).

Given these applications, technologists now are focusing their time and talents on miniaturizing

spacecraft electronics, detectors, telescopes, and other essential components, said Ted Swanson, senior technologist for strategic integration with Goddard's Office of the Chief Technologist. They also are investigating new materials and fabrication techniques that reduce instrument size, mass, and manufacturing costs — all while improving instrument performance and ability, he said.

"Advancement in this area isn't necessarily a new trend," observed Michael Johnson, chief technologist for Goddard's Applied Engineering Technology Directorate. "But our current fiscal environment certainly is increasing the importance of doing science with fewer dollars."

## Other Trends

One trend that Cutlip thinks may grow legs is "building to cost" — the idea that mission planners receive a set budget and build to those financial parameters. "They would tell us what they could give us in terms of science and performance for that budget," he said. "Frankly, I think the approach has the potential to drive innovation."

Just as important, these experts said, is culture. "We're trying to invigorate a culture of innovation," Cutlip said. "We're looking for the big leap," he added. "We can't afford to fund the incremental leaps in capability. If we're keeping pace with industry, we're not doing our job. That's why we're here — to be leaders in space technology." ♦

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## The Good-Humored Expert: A Tribute to Wayne R. Powell (1941-2014)

A few days after being released from a rehabilitation hospital — where he was treated for injuries sustained in a serious car accident — the always-irrepressible Wayne R. Powell called his colleague from his Pocomoke City home on Maryland's Eastern Shore.

"He called me several times wanting to get his work laptop, his 'television typewriter' — as he called it — so he could start teleworking the following week," recalled Dan Mullinix, a colleague of Powell's at the Wallops Flight Facility, where Powell had worked as a civil servant for nearly 40 years. "I took his laptop to him after work, spent some time with both him and his wife, Bonnie, and we successfully got his 'television typewriter' going and connected to his wireless router. Although he was still in some pain, he was otherwise the talkative, joking Wayne that we knew and loved."



The next morning, Powell collapsed. The paramedics could not revive him.

"We were all looking forward to Wayne's recovery and his return to work," said Goddard Chief Technologist Peter Hughes, who leads the Goddard Technology Federation of which Powell had been a long-time participant. "Always cheerful, Wayne was ready to share his considerable expertise in suborbital platforms and range services whenever asked."

Born in 1941 in Salisbury, Maryland, Powell earned a B.S. degree in mechanical engineering and a Master's in electrical engineering from Old Dominion University in Norfolk, Virginia, where he taught until joining Computer Sciences Corporation at Wallops Island in 1970. Six years later, he joined NASA, supporting rocket launches.

"His vast technical knowledge helped us position the Wallops Flight Facility as the go-to venue for launch services, suborbital communications, and other capabilities that continue to enable important scientific investigations," Hughes added. "Words simply do not convey my sadness and sense of tremendous loss at Wayne's untimely passing."

Although Wayne had significant technical expertise, "he was quick to ask tough questions and was humble enough to seek inputs from others,"

recalled Steve Nelson, assistant director of the Applied Engineering and Technology Directorate at Wallops. "He found humor in everyday situations, and had a booming, infectious laugh that brightened your day. I will miss him."

His wife, a sister, several nieces and nephews, and his pet cat, Holly, survive him. ♦



Goddard's Emerging Technologies

**CuttingEdge** is published quarterly by the Office of the Chief Technologist at the Goddard Space Flight

Center in Greenbelt, Md. Formerly known as *Goddard Tech Trends*, the publication describes the emerging, potentially transformative technologies that Goddard is pursuing to help NASA achieve its mission. For more information about Goddard technology, visit the website listed below or contact Chief Technologist Peter Hughes, [Peter.M.Hughes@nasa.gov](mailto:Peter.M.Hughes@nasa.gov). If you wish to be placed on the publication's distribution list, contact Editor Lori Keeseey, [Lori.J.Keeseey@nasa.gov](mailto:Lori.J.Keeseey@nasa.gov). NP-2014-10-193-GSFC